

YIELD, IRRIGATION PRODUCTION EFFICIENCY AND ECONOMIC RETURNS OF BROCCOLI UNDER VARIABLE DRIP IRRIGATION AND LATERAL SPACING

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ABSTRACT

Field studies were carried out for 2 years (2001 – 2003) on clay loam soil to determine the effect of variable irrigation (50, 100, 150 and 200% of pan evaporation replenishment) and lateral spacing (0.5 and 1.0m) on yield, irrigation production efficiency and economic return of broccoli (*Brassica oleracea*). The irrigation was applied when sum of daily pan evaporation (5 years) from United States Weather Bureau (USWB) Class A open pan reached approximately up to 16.3mm after accounting for rainfall. The crop was irrigated by drip irrigation system. Irrigation at 150% of pan evaporation replenishment and 0.5m lateral spacing resulted in higher marketable yield of primary and secondary flowers. A further increase in irrigation amount resulted from 200% pan evaporation replenishment reduced marketable flower yield significantly. The higher irrigation production efficiency was recorded at 50% of pan evaporation replenishment and 0.5m lateral spacing and it decreased significantly with an increase in irrigation amount and lateral spacing. Irrigation at 150% of pan evaporation replenishment resulted in a higher net return and benefit-cost ratio. The lateral spacing of 1.0m gave higher net return and benefit-cost ratio as compared to lateral spacing of 0.5m. The seasonal water applied and marketable flower yield, gross return, net return and benefit-cost ratio exhibited quadratic relationship which can be used for optimising economic return of broccoli under variable irrigation and lateral spacing. The results revealed that drip irrigation system is profitable for broccoli production in spite of high initial investment.

Keywords: Drip Irrigation, Variable irrigation, Lateral spacing, yield, economic return, and broccoli

INTRODUCTION

Water resource in the northern plain region of India is becoming scarce and expensive to exploit due to erratic rainfall and over-exploitation of surface and subsurface water resources. Due

to fast economic growth and urbanisation, the competition of limited water resources for agriculture, domestic and industrial needs is increasing considerably. The present irrigation management practices in this region results in heavy

conveyance and water application losses, which in turn leads to water logging, salinity and ground water contamination. For sustainable crop production to feed the ever-growing population in India, it is essential to develop efficient and economically viable irrigation management practices in order to irrigate more land area with existing limited water resources.

Irrigation scheduling is a critical management input to ensure adequate soil moisture for optimum plant growth, yield, quality, water use efficiency and economic returns. Irrigation scheduling which determines the timing and amount of irrigation is governed by many factors but the microclimate plays the most important role. Therefore, it is essential to develop irrigation scheduling techniques under prevailing climatic conditions. For the last 2–3 decades, numerous studies have been carried out on the development and evaluation of irrigation scheduling techniques under a wide range of agro-climatic conditions (Jensen *et al.*, 1970; Hiller and Howell 1973; Steele *et al.* 1997; Mahdi *et al.* 1977; Misra and Pant 1981; Imtiyaz and Shiromani 1990; Wanjura *et al.* 1990; Imtiyaz *et al.* 2000 d). The meteorologically based irrigation scheduling approach such as pan evaporation replenishment, cumulative pan evaporation and the ratio between irrigation water and cumulative pan evaporation was used extensively due to its simplicity, data availability and higher degree of adoptability (Prihar *et al.* 1974; Singh 1987; Singh and Mohan 1994; Singh *et al.* 1997; Imtiyaz *et al.* 2000b, c). Imtiyaz *et al.* 2000a reported the higher marketable yield, irrigation production efficiency and net return of broccoli with irrigation at 80% of pan evaporation replenishment under the climatic condition of north western region of Botswana.

Surface irrigation is the most common method for vegetable, fruit and flower crops in this region. The overall efficiencies of surface irrigation methods are considerably lower as compared to drip, micro-sprinkler and overhead sprinkler irrigation. Due to increasing water scarcity, the

Government of India is encouraging farmers to adopt efficient irrigation methods and, thereby, to feed the ever-growing population. The Drip irrigation with its ability for small but frequent water application have been found superior in terms of water economy, yield and water use/irrigation production efficiency (Theodor 1980; Pruitt *et al.* 1984; Srivastava *et al.* 1994; Hanson *et al.* 1997; Fekadu and Teshome 1998; Imtiyaz *et al.* 2000d). The initial investment of drip irrigation is considerably higher as compared to conventional surface irrigation methods. The cost of laterals and emitters are the major factors influencing initial investment. Therefore, it is necessary to develop strategies in order to reduce the cost of lateral network and emitters per hectare to make drip irrigation affordable to the farming community in this region. Devitt and Miller (1988) investigated several lateral spacings on two soils for Bermuda grass concluding that 0.6m spacing was acceptable for a sandy loam, but a closer spacing would be required for clay. Camp *et al.* (1997) reported higher cotton yields with every row drip line placement compared with alternate row placement. Lamm *et al.* (1995) used alternate row spacing for corn and reported water savings approaching 25%. However, more specific information is required for specific soil-crop-climatic combinations.

Broccoli is an important vegetable crop but the importance of this vegetable is limited in India due to the lack of information on irrigation management, yield potential and economic returns. Broccoli is known as the crown jewel of nutrition because it is rich in vitamins A, B, B₂ and C. Drip irrigation is popular in several agro-climatic zones in India except in the state of Uttar Pradesh mainly due to the lack of information on irrigation scheduling techniques and economic viability of the system. Therefore, the objective of the present study was to investigate the effect of variable irrigation and lateral spacing of drip irrigation on marketable yield, irrigation production efficiency and economic return of broccoli in a semi-arid climate.

MATERIALS AND METHODS

Field experiments were conducted at the Irrigation Research Farm of Allahabad Agricultural Institute - Deemed University, Allahabad, India (25°27' N, 81°E, 98m above mean sea level) for two consecutive winter seasons (2001–2003) in order to examine the effect of variable irrigation and lateral spacing on yield, irrigation production efficiency and economic return of broccoli. The climate in this part of the country has been classified as semi-arid. The climatic parameters during the crop growing periods are summarized in Table 1. The soil of the experimental field was fertile clay loam (35.5% sand, 25.8% silt and 36.6% clay) with average bulk density of 1.31 g/cm³. The soil moisture content at field capacity (-1/3 bar) and wilting point (-15 bar) were 19.5% and 9.1% on dry weight basis. The plant available soil moisture was 136mm/m.

The experiments were laid out in a two-factor complete randomised block design with three replications. The area of each experimental plot was 15m². A buffer zone spacing of 1.0m was provided between the plots. Prior to transplanting, the experimental field of broccoli received 68 kg/ha N, 94.3 kg/ha P₂O₅ and 62.5 kg/ha K₂O. The experimental plot of broccoli received 66 kg/ha N after 5 and 7 weeks of transplanting. Broccoli (hybrid var. Fiesta) seed was sown on 26 October 2001 and 30 October 2002 in the nursery at a depth of 0.05m with a spacing of 10 cm between the rows. Broccoli seedlings were transplanted on 7 December in 2001 and 10 December in 2002 at a plant spacing of 0.5m x 0.5m.

The experiment consisted of four irrigation levels, i.e. the amount of water in different treat-

Table 1: Yield and irrigation production efficiency of broccoli as influenced by irrigation levels and lateral spacing

Treatment (Pan evaporation replenishment, %)	Mean marketable yield (t/ha)						Mean irrigation production efficiency (kg/m ³)	
	Primary flowers, t/ha		Secondary flowers, t/ha		Total (primary + Secondary), t/ha			
	2002	2003	2002	2003	2002	2003	2002	2003
50	17.53	18.20	1.45	1.55	18.98	19.55	16.62	16.80
100	22.85	23.75	2.70	3.00	25.30	26.50	12.30	12.86
150	26.97	28.25	4.85	5.00	31.80	33.05	10.72	11.06
200	24.57	26.00	3.55	3.60	28.10	29.00	7.22	7.51
LSD (0.05)	0.86	0.98	0.18	0.26	0.90	0.75	0.59	0.48
Lateral spacing, m								
0.5	23.78	24.67	3.41	3.52	27.18	28.00	12.42	12.75
1.0	22.18	23.42	2.88	3.05	24.94	26.05	11.01	11.45
LSD (0.05)	0.61	0.75	0.12	0.19	0.64	0.56	0.42	0.48
Interaction LSD (0.05)	1.21	1.02	0.25	0.29	1.27	1.38	0.77	0.67

ments was 50, 100, 150 and 200% USWB class A pan evaporation replenishment and two lateral spacings i.e. 0.5m (lateral at every row) and 1.0m (lateral at every alternate rows). The pan was located at a Agro-meteorological Station adjacent to the experimental site with a moderate grass cover. Crop was irrigated when the sum of the daily mean (5 years) of pan evaporation reached approximately a pre-determined value of 16.3mm (rooting depth in m x plant available soil moisture in mm/m x readily available soil moisture in fraction). The crops were irrigated by the surface drip irrigation method. The drip irrigation system was designed and installed to meet the objectives of the experiment. The irrigation water was pumped directly from tube-well to the concrete tank and thereafter it was pumped from the tank to the drip irrigation system. Screen filter was installed on the main line to minimise dripper blockage. The 50mm diameter PVC pipes and 12mm diameter Low Density Polyethylene pipes were used for the sub-main and laterals respectively. The laterals were laid on each row at 0.5m spacing) as well as in alternate rows at 1.0m spacing). The broccoli was watered by 4 ℓ/h non-pressure compensated on-line drippers. The spacing between drippers was 0.5m. The experimental plot was connected by a control valve in order to deliver the desired amount of water. The sub-main was connected to a water meter and control valve. During the first 2 weeks, the crops were irrigated daily at 75% of pan evaporation losses in order to establish newly planted seeds. Standard cultural practices were adopted during the crop-growing season. Crop was harvested from 18 – 28 March in both years, depending upon the maturity of primary and secondary flowers. Crop yield was obtained upon the weight of the flowers and it was measured in terms of tones/ha. Further irrigation production efficiency was obtained by the formula,

$$\text{Irrigation Production Efficiency, Kg/m}^3 = \frac{\text{Marketable Yield, Kg/ha}}{\text{Total Water Applied, m}^3 / \text{ha}} \quad \dots (1)$$

In order to assess the economic viability of the drip irrigation system under variable irrigation and lateral spacings, both fixed and operating costs were considered. Total cost, gross return and net return were estimated on the following assumptions:

Salvage value of the components	= 0
Useful life of tube-well, pump, motor and pump house	= 25 years
Useful life of drip irrigation system	= 7 years
Useful life of weeding and spraying equipments	= 7 years
Interest rate	= 14% p.a.
Repair and maintenance	= 7.5%
Number of crops per year	= 2

The fixed cost was calculated, including water development (tube-well, pump, motor, pump-house and other accessories) and drip irrigation system (low density polyethylene pipe for main, sub main and laterals, filters, fertiliser unit, pressure gauges, control valves, water meter, drippers and other accessories). The annual fixed cost for water development and irrigation system under variable irrigation and lateral spacing was calculated separately by the following approach (James and Lee, 1971):

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

Where,

CRF = Capital recovery factor

i = interest rate (fraction)

n = Useful life of components (years)

$$\text{Annual fixed cost/ha} = \text{CRF} \times \text{fixed cost/ha} \quad (3)$$

$$\text{Fixed cost/ha/season} = \frac{\text{Annual fixed cost/ha}}{2} \quad (4)$$

The operating cost including labour (system installation, planting, irrigation, weeding, cultivation, fertiliser application, spraying and harvesting, etc.), land preparation, seeds, fertilisers, chemicals, water pumping and repair and maintenance was calculated. The gross revenue for different irrigation levels and lateral spacing was calculated, taking into consideration the marketable yield and current wholesale price of broccoli. Subsequently, the net returns under different irrigation levels and lateral spacings were calculated considering the total cost of production and gross revenue.

The benefit-cost ratio (B/C) under variable irrigation items and lateral spacing was calculated as follows:

$$B/C = \frac{\text{Gross revenue (Rs/ha)}}{\text{Total cost of production (Rs/ha)}} \quad (5)$$

RESULTS AND DISCUSSION

Yield and irrigation production efficiency

In both seasons (2002 and 2003), irrigation levels significantly influenced the marketable yield of broccoli (Table 1). In both the years, the highest

marketable yield of primary (26.97 – 28.25 t/ha) and secondary (4.85 – 5.00 t/ha) flowers was observed when irrigation during the crop growing season was applied at 150% of pan evaporation replenishment mainly due to higher mean flower weight. A further increase in the amount of irrigation resulted from 200% of pan evaporation replenishment reducing the marketable yield of primary and secondary flowers due to significant reduction in mean flower weight. The lower marketable yield for 50 and 100% of pan evaporation replenishment resulted from a significant decrease in flower weight. Lateral spacing had significant effect on mean flower weight and marketable yield of primary and secondary flowers (Table 2). The irrigation production efficiency of broccoli was influenced by irrigation levels and lateral spacing. In both years the highest irrigation production efficiency (16.62 – 16.80 kg/m³) was recorded at 50% pan evaporation replenishment. Irrigation at 200% of pan evaporation replenishment resulted in significantly minimum irrigation production efficiency (7.22-7.51 kg/m³) because it increased the seasonal water application but decreased the marketable flower yield. The significantly higher irrigation production efficiency (12.42-12.75 kg/m³)

Table 2: Economic analysis for broccoli under different irrigation schedules and lateral spacing (average data of 2 years).

Treatment (Pan evaporation replenishment, %)	0.5m lateral spacing (LS ₁)				1.0m lateral spacing (LS ₂)			
	Total cost of production	Gross Return	Net Return	Benefit cost ratio	Total cost of production	Gross Return	Net Return	Benefit cost ratio
	US\$/ha	US\$/ha	US\$/ha		US\$/ha	US\$/ha	US\$/ha	
50	1935	5827	3893	3.00	1598	4691	3093	2.93
100	1955	7423	5468	3.78	1618	6718	5099	4.14
150	1975	8986	7011	4.54	1639	8723	7084	5.35
200	1996	7882	5886	3.93	1659	7705	6046	4.65

Note: The price of broccoli is taken as US\$ 0.27 (Approximately Rs or INR. 12/- kg)
1 US\$ = Approximately Rs.44

was obtained when laterals were provided for every row of the crop. In all the irrigation levels, the maximum irrigation production efficiency was obtained when laterals were provided in every crop rows as compared with laterals at alternate rows (Table 2). The higher marketable flower yield and flower weight was recorded at 150% of pan evaporation replenishment, whereas irrigation at 50% of pan evaporation replenishment gave the higher irrigation production efficiency when laterals were provided at 0.5m spacing. Similar trends were reported by many researchers elsewhere for other crops, irrigation regimes and climatic conditions (Phene and Sanders 1976; Devitt and Miller 1988; Singh and Mohan 1994; Imtiyaz *et al.* 2000c, 2002).

Economic Returns

The total cost of production and net return of broccoli under different irrigation levels and lateral spacings are presented in Table 2. The total cost of production (fixed and operating costs) increased slightly with an increase in pan evaporation replenishment (irrigation levels) because the pumping cost was insignificant as compared to the total cost of production. The total cost of production was considerably higher for 0.5m lateral spacing as compared to 1.0m lateral spacing due to higher fixed cost resulting from considerably higher number of drippers/ha and lateral length. The repair and maintenance cost for 0.5m and 1.0m lateral spacing contributed 2.86% and 2.02% respectively to the total cost of production. The labour cost to perform major farm activities for 0.5 and 1.0m lateral spacing contributed 27.80% and 33.48% respectively to the total cost of production. The cost of land preparation, land rent, seed, fertilizers and chemicals for 0.5m lateral spacing contributed 26.78 and 32.25% respectively to the total cost of production. The net return of broccoli for both 0.5m and 1.0m lateral spacing increased sharply from 50 to 100% of pan evaporation replenishment due to sharp increase in marketable flower yield. A further increase in irrigation level resulted from

200% of pan evaporation replenishment decreasing the net return because it increased the total cost of production, but decreased the gross return. The maximum net return for 0.5m and 1.0m lateral spacing was US\$ 7011/ha and US\$ 7084/ha respectively (Table 2). The benefit cost ratio (B/C), which indicates gross revenue per unit investment was also influenced by irrigation level and lateral spacing. The irrigation at 150% of pan evaporation replenishment gave the maximum benefit cost ratio for 0.5m (4.54) and 1.0m (5.35) lateral spacing because increase in gross return was higher as compared to total cost of production. However, the benefit cost ratio for 1.0m lateral spacing at 100, 150 and 200% of pan evaporation replenishment was higher than 0.5m lateral spacing mainly due to higher reduction in total cost of production as compared with gross return (Table 2). The results revealed that under different lateral spacing irrigation at 150% of pan evaporation replenishment gave the maximum gross return, net return and benefit cost ratio. The overall results under different lateral spacings revealed that irrigation at 150% of pan evaporation replenishment gave the maximum gross return, net return and benefit cost ratio. Similar results were reported by some researchers under wide variety of irrigation systems and regimes, soil crop and climatic conditions (Srivastava *et al.* 1994; Singh *et al.* 1997; Tiwari and Reddy 1997; Imtiyaz *et al.* 2000a,b, d, e and 2002).

Relationship between water applied, yield, gross return, net return and benefit cost ratio

The relationship between seasonal water applied versus marketable flower yield, gross return, net return and B/C ratio are shown in Fig. 1, 2, 3 and 4. The seasonal water applied to broccoli ranged from 114 – 387 and 116 – 386mm whereas marketable yield for 0.5m and 1.0m lateral spacings ranged from 18.98 – 31.80 and 19.55 – 29.00 t/ha respectively. The seasonal water applied to broccoli for 0.5m ($R^2 = 0.9387$) and 1.0m ($R^2 = 0.9460$) lateral spacing exhibited strong quadratic relationship. The marketable yield of broccoli

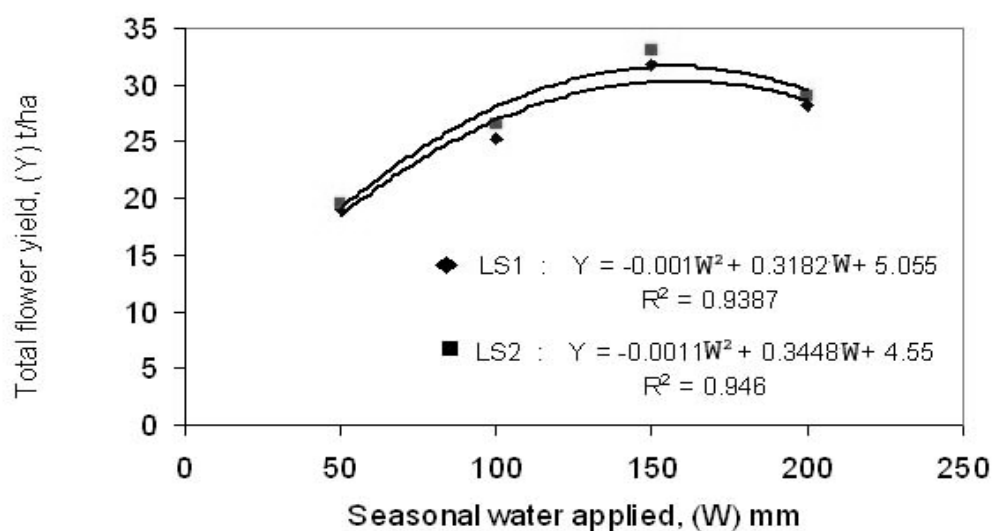


Fig. 1: Relationship between seasonal water applied and total flower yield of Broccoli for 0.5m and 1.0m lateral spacing

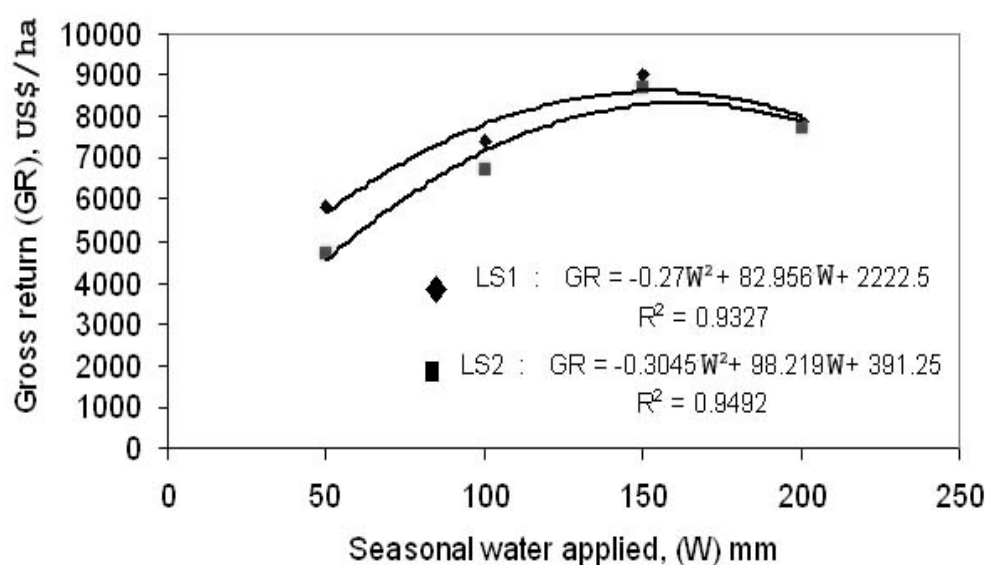


Fig. 2: Relationship between Seasonal water applied and gross return of Broccoli for 0.5m and 1.0m lateral spacing

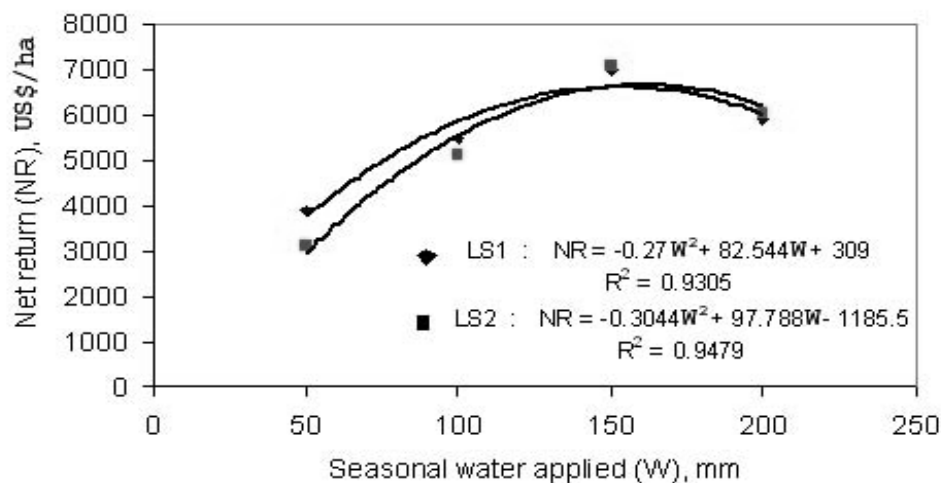


Fig. 3: Relationship between seasonal water applied and net return of Broccoli for 0.5m and 1.0m lateral spacing

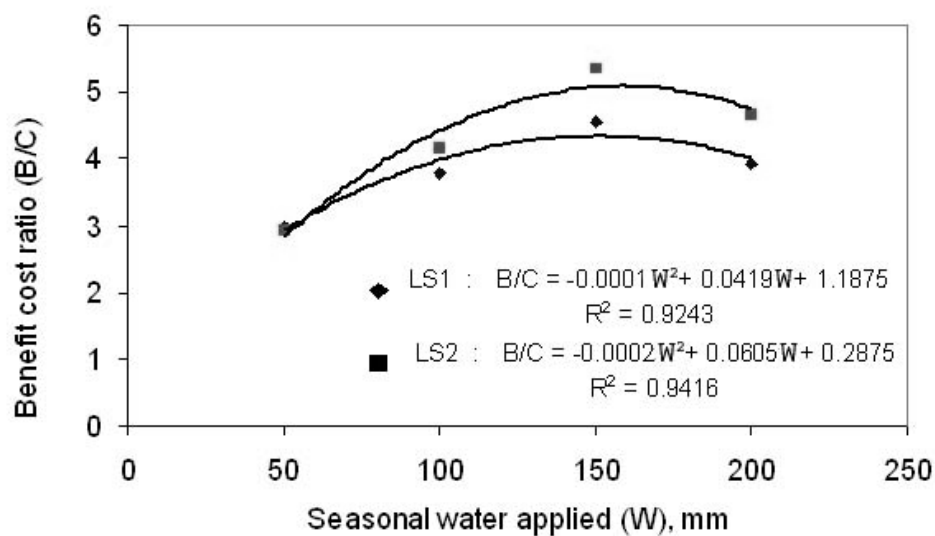


Fig. 4: Relationship between seasonal water applied and benefit cost ratio of Broccoli for 0.5m and 1.0m lateral spacing

increased with an increase in seasonal water applied and gross return for 0.5m and 1.0m lateral spacing respectively and thereafter it tended to decline (Fig. 1). The relationship between seasonal water applied for 0.5m and 1.0m lateral spacing ranged from 5827 to 8986 and 4691 to 8723 US\$ /ha respectively. The seasonal water applied and gross return for 0.5m ($R^2 = 0.9327$) and 1.0m ($R^2 = 0.9492$) lateral spacing exhibited a strong quadratic relationship. The gross return of broccoli increased with an increase in seasonal water applied for 0.5m and 1.0m lateral spacing respectively and thereafter, gross return tended to decline (Fig. 2). The relationship between seasonal water applied and net return of broccoli for 0.5m and 1.0m lateral spacing ranged from 3893 to 7011 US\$/ha and 3093 to 7084 US\$/ha, respectively. The seasonal water applied and net return for 0.5m ($R^2 = 0.9305$) and 1.0m ($R^2 = 0.9479$) lateral spacing exhibited strong quadratic relationship. The net return of broccoli increased with an increase in seasonal water applied for 0.5m and 1.0m lateral spacing respectively and thereafter gross return tended to decline (Fig. 3). The relationship between seasonal water applied and benefit cost ratio for 0.5m and 1.0m lateral spacing ranged from 3.00 to 4.54 and 2.93 – 5.35 respectively. The seasonal water applied and benefit cost ratio for 0.5m ($R^2 = 0.9243$) and 1.0m ($R^2 = 0.9416$) lateral spacing exhibited strong quadratic relationship. The benefit cost ratio of broccoli increased with an increase in seasonal water applied for 0.5m and 1.0m lateral spacing respectively and thereafter it tended to decline (Fig. 4). The fitted regression model relating pan evaporation replenishment and benefit cost ratio under different irrigation levels and lateral spacing could be used for irrigation scheduling for optimum economic returns.

In spite of some variation, the overall results showed strong quadratic relationship between seasonal water applied/irrigation levels and gross return, net return and benefit cost ratio for broccoli under varying lateral spacing. Tiwari and Reddy (1997) reported similar results for banana.

CONCLUSION

The experimental results for both years showed that irrigation with 150% evaporation replenishment resulted in the highest marketable yield of winter broccoli. Irrigation at 50% pan evaporation replenishment produced higher irrigation production efficiency. Irrigation with 200% pan evaporation replenishment reduced the irrigation production efficiency because it increased the seasonal water application considerably without a significant improvement in marketable yield. The net return for broccoli increased sharply from 50 to 150% pan evaporation replenishment for 0.5m and 1.0m lateral spacing. In both year's seasonal water applied and marketable yield of broccoli for 0.5m and 1.0m lateral spacing exhibited strong quadratic relationship. Irrigation water production functions developed in the present investigations can be used for allocating water within and between the above mentioned crops, comparing irrigation production efficiency and economic analysis. Finally the overall results clearly suggest that in order to obtain an optimum yield, irrigation production efficiency and net return of broccoli in the northern plain of India, crops during the winter season should be irrigated at 150% of pan evaporation replenishment and the lateral spacing 1.0m gave the highest net return for broccoli. Furthermore, an irrigation management approach using pan evaporation data is simple and can be adopted easily by farmers. In spite of the high initial investment, drip irrigation for vegetable production in Allahabad region, India is highly profitable because of the high market price of the produce. Clogging of the drippers is the main concern, but it can be minimised by using appropriate filters and flushing out the main, sub main and lateral lines regularly.

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